U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-251 985

COMBUSTION OF WOOD RESIDUE IN CONICAL (WIGWAM) BURNERS, EMISSION CONTROLS AND ALTERNATIVES

PEDCo-Environmental Specialists, Incorporated

Prepared for
Environmental Protection Agency

October 1975

EPA 340/1-76-002 120102
FEBRUARY 1976

Stationary Source Enforcement Series

PB 251 985

EMISSION CONTROL AND ALTERNATIVES

COMBUSTION OF WOOD RESIDUE IN CONICAL WIGWAM BURNERS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Enforcement
Office of General Enforcement
Washington, D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

82

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 340/1-76-002	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Combustion of Wood Residue in Conical (Wigwam) Burners, Emission Controls and Alternatives		5. REPORT DATE October 1975
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Dr. Richard W. Boubel, Oregon State University N. Stephen Walsh, PEDCo-Environmental		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS PEDCo-Environmental Specialists, Inc. Suite 13, Atkinson Square Cincinnati, Ohio 45246		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. Contract No. 68-01-3150 Task Order No. 5
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Division of Stationary Source Enforcement Washington, D. C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The lumber and plywood manufacturing process generate large quantities of wood residue and waste material, much of which is incinerated in conical or "wigwam" burners. This report provides technical information on air pollution control techniques and alternatives for conical burners. Background information is given regarding the design, operation and combustion activities, including fuel composition. Air pollution emissions, both gaseous and particulate, are calculated and current regulations are reviewed. Modifications to existing burners are suggested as well as alternative methods of residue disposal. Capital and operating costs and approximate time schedules are given for both modifications and alternatives to wigwam burners.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Burners Wood Wastes Combustion Air Pollution Industrial Wastes Waste Disposal	Wigwam Burners	13B

PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 82
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE $5.00 - 2.25

EPA Form 2220-1 (9-73)

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Contract No. 68-01-3150
Task No. 5
Technical Service Area No. 4
PN-3210-4-E

EPA Project Officer: James E. Casey

Prepared for

U.S. Environmental Protection Agency
Division of Stationary Source Enforcement
Washington, D.C. 20460

October, 1975

This report was furnished to the U.S. Environmental Protection Agency by PEDCo-Environmental Specialists, Inc., Cincinnati, Ohio, in fulfillment of Contract No. 68-01-3150 (Task No. 5). The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency.

ACKNOWLEDGMENT

This report was prepared for the U.S. Environmental Protection Agency by PEDCo-Environmental Specialists, Inc., Cincinnati, Ohio. Mr. George Jutze was the PEDCo Project Manager. The principal author of the report was Dr. Richard W. Boubel, Oregon State University, Corvallis, Oregon. Mr. Steve Walsh assisted in preparation of the final draft.

Mr. James E. Casey was the Project Officer for the U.S. Environmental Protection Agency. The authors appreciate the assistance and cooperation extended by Mr. Casey, and staff members of EPA Regional Office VIII and Oregon State University.

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1. INTRODUCTION

THE WOOD RESIDUE PROBLEM

The lumber and plywood manufacturing processes generate large quantities of wood residue or waste material. Some of this residue or waste material is converted to useful by-products such as chips for pulp, particle board, Presto logs, and even heat which is utilized for electrical power or steam. The remaining residue may be incinerated at the mill site in a tepee-shaped, single-walled, steel waste burner. The amount and type of residue fed to the waste burner depends upon the practices of the particular mill, species of log being processed, time of year, and mill location with respect to by-product markets. All of these factors are variable so the fuel fed to the burner may be expected to also vary widely with time.

Since only approximately half the log which enters the mill is converted to lumber or plywood, the volume of residue produced nearly equals the volume of the primary product produced by the mill. While many mills utilize all of their residue for by-products, other mills incinerate all of it. Therefore, it can be stated that utilization of wood residue varies from 0 to 100 percent. Incineration in wigwam waste burners is the usual method of wood waste disposal when utilization is something less than 100 percent.[1,2]

Wigwam waste burners at some operations have done a creditable job. Waste products delivered to the burners have been consumed with only a minimum of smoke and cinders (unburned material) issuing from the top with the exit gases. At other operations, the great quantities of smoke produced have caused severe air pollution problems and hazardous visibility conditions for automobile and air travel. Cinders ejected not only have created a nuisance to owners of property in surrounding areas, but also have constituted a fire hazard.

HISTORY OF WOOD WASTE BURNERS

During the first 20 years of this century, many types of waste burners were designed. Some were designed for complete combustion, some for low initial cost, and others for low maintenance. Most accounts described design and construction of new burners and predicted results, but actual success of operation or economy of maintenance of burners which had been in operation an appreciable length of time was seldom mentioned.

The steel-jacketed, brick-lined, cylindrical burner was perhaps the most common type. A shell made from steel plates was lined with common brick and firebrick in the following manner: two courses of common brick and 1 course of firebrick from the base upward for 15 feet; 1 course of common and 1 of firebrick from 15 feet to 40 feet; 1 course of firebrick from 40 feet to 75 feet; and 1 course of common brick above 75 feet. Foundations were made of brick or concrete, and often consisted of a central core several feet in diameter and an outer base on which the burner rested. There were grates between core and base. Fuel dropped from about 40 feet onto the central core. The top of the burner was covered with a 3 by 3 mesh, 14-gauge wire screen. The base area was from 3.5 to 5.5 square feet per 1000 board feet of mill output. Exteriors were often painted or tarred to prevent corrosion. Maintenance costs were high because the brick-work had to be replaced annually.

Some steel, water-cooled burners were used which had no brick lining but, instead, had a watertight steel jacket surrounding the inner shell, which was from 12 to 15 inches thick. These burners were constructed in all sizes up to 50 feet in diameter and 115 feet in height. Paint and asphalt were used to protect the outer surface. Very few were built, however, because of high construction and maintenance costs.

Open pit fires were used then, as they sometimes are today. These consisted of a semicircular screen or wall rising 20 to 30 feet on the side of the fire toward the mill.

Brick shell burners were cylindrical and similar to brick-lined shell burners, except that they were shorter. Steel straps were placed around them for support.

An air-cooled burner was placed on the market in 1916. It had a conical base and a cylindrical stack without any brick lining. The foundation was a concrete wall 1 foot thick and extending 2 feet above the grate level. The framework was made of structural steel and iron pipe, with an outside covering of medium-weight steel plates riveted together. The conical shape placed the base of the burner farther away from the fire, and air circulation cooled it. These burners cost 40 to 50 percent less than brick-lined steel burners.

This was the beginning of the tepee burner commonly in use today. Most builders have abandoned the cylindrical stack and now construct burners which are conical from base to screen.

Most tepee burners have two screens at the top - a flat, horizontal screen and a hemispherical one. Tangential openings at the base to supply overfire air to the fire have been used for many years. Underfire air is usually supplied by one or two blowers to cones or burner grates. Some burners are elevated to provide tunnels below the grate level to admit underfire air.

The practice of building prefabricated burners has been developed since 1946. These are built in sections, running from the base to the screens. The structural framework is on the outside, with the plates on the inside. The burners are raised into place on location and bolted together in a short time. They can be dismantled easily, transported, and re-erected at another location.

ENFORCEMENT ACTIONS

Early enforcement actions were taken by fire insurance underwriting agencies which specified design and operation to minimize burning cinder discharge. These regulations were concerned with screen size openings, burner sizing, fuel delivery rates, and maintenance of the burner.

Air pollution regulations appeared during the early 1960's. Most of the first regulations were simplistic approaches relating to dustfall downwind from burners and control of the burners to minimize visual smoke. From the mid 1960's until the early 1970's many state and regional air pollution control agencies adopted regulations covering burner design and construction to minimize particulate emissions, particulate emission standards (grains per cubic foot), and opacity regulations based on a modified Ringelmann scale (0 - 100% opacity). No Federal Standards concerning emissions have been promulgated nor have any regulations been adapted for gaseous emissions.

Enforcement actions based on non-compliance of emission or design standards have been upheld in most cases to date. Many burners have been eliminated as a result of these enforcement actions and the mills concerned have converted to alternative means of residue disposal.

2. COMBUSTION IN WIGWAM BURNERS

PROPERTIES OF WOOD AS A FUEL

Wood is probably man's oldest fuel and the combustion of wood probably man's first attempt to use a chemical process for his betterment. Combustion is defined as the union of a substance with oxygen accompanied by the evolution of heat and light. Even though scientists do not completely understand all the mechanisms of combustion, they can use the combustion reaction to their advantage. Combustion may be used to produce energy, as in an automobile or a steam generator, or as a destructive reaction to eliminate an unusable material. The latter is the case in the waste burner.

Ultimate Analysis*

Wood can be a widely varying fuel with different physical and chemical properties, depending upon the species, age, location, etc. A chemical analysis for dry Douglas-fir would indicate the following percentages of material:

Hydrogen	6.3%
Carbon	52.3%
Nitrogen	0.1%
Oxygen	40.5%
Ash	0.8%

Such an analysis is called an Ultimate Analysis. All non-combustibles are lumped together as ash.

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*For a complete discussion of fuel analysis, see: Mingle, J.G., and R.W. Boubel. Proximate Analysis of Some Western Wood and Bark. Wood Science. 1:1. pp 29-36. July, 1968.

Proximate Analysis

Another type of analysis used by combustion engineers is the Proximate Analysis. This analysis indicates how the fuel will be burned. The Proximate Analysis for dry Douglas-fir would be:

Volatile Matter	82.0%
Fixed Carbon	17.2%
Ash	0.8%

The heating values of wood will vary considerably. Dry Douglas-fir has a heating value of 9,050 BTU per pound. This is only about one-half the heating value of petroleum products. The main reason it is lower is the high oxygen content which in this respect dilutes the heating value of the wood.

Steps in Wood Combustion

The steps in wood combustion are rather specific and well defined. Assume a pile of fuel, such as in a tepee burner; fresh fuel falls on the top of the pile where it is dried as the moisture is driven off. This is an endothermic process in that it requires heat.

The volatiles are next distilled from the wood. These may be combustible gases (hydrocarbons) or noncombustibles (oxygen and nitrogen). The process is endothermic because it requires heat for the distillation and also exothermic because the volatile gases are burned. This combustion takes place above the fuel pile where sufficient oxygen is available. The combustion reactions of interest are: (1) $C + O_2 \rightarrow CO_2$ and (2) $2H_2 + O_2 \rightarrow 2H_2O$.

After all the volatile matter has been distilled, all that remains is the fixed carbon. This is the material of which briquets, which are used in home barbecues, are made. This fixed carbon is burned in the fuel pile if sufficient oxygen is available ($C + O_2 \rightarrow CO_2$). The heat is all released within the fuel pile if the combustion is complete. If not enough oxygen from the air is available, the reaction in the pile is: $2C + O_2 \rightarrow 2\ CO$, and only a portion of the heat is released within the pile. The remainder of the reaction takes place over the pile where sufficient oxygen is available: $2\ CO + O_2 \rightarrow 2\ CO_2$. Additional heat is released in this reaction.

The remaining material that is left after combustion is the ash. This collects at the base of the pile and must be periodically disposed of.

Combustion in a Tepee Burner

When we analyze the combustion in a waste burner, we have simply enclosed the open fuel pile within a shell. Figure 2-1 illustrates such a situation.

To dry the incoming fuel, the combustion products H_2O and CO_2 may be used. These were generated from the combustion of H_2 and C. O_2 and N_2, which were forced through the hot fuel pile by the forced-draft system, help dry the fuel. Radiant heat from the shell will also help to dry the fuel. The radiant heat is a function of the absolute temperature squared, so a cool shell doesn't help dry much fuel.

To distill the volatiles, the hot CO_2 and CO are available from the combustion of the fixed carbon below. The hot O_2 and N_2, which were forced through the burning bed, are available as heat sources. Again the radiant heat from the shell is available.

The fixed carbon is burned in the pile. If enough forced-draft air is supplied, it burns to CO_2 in the pile.

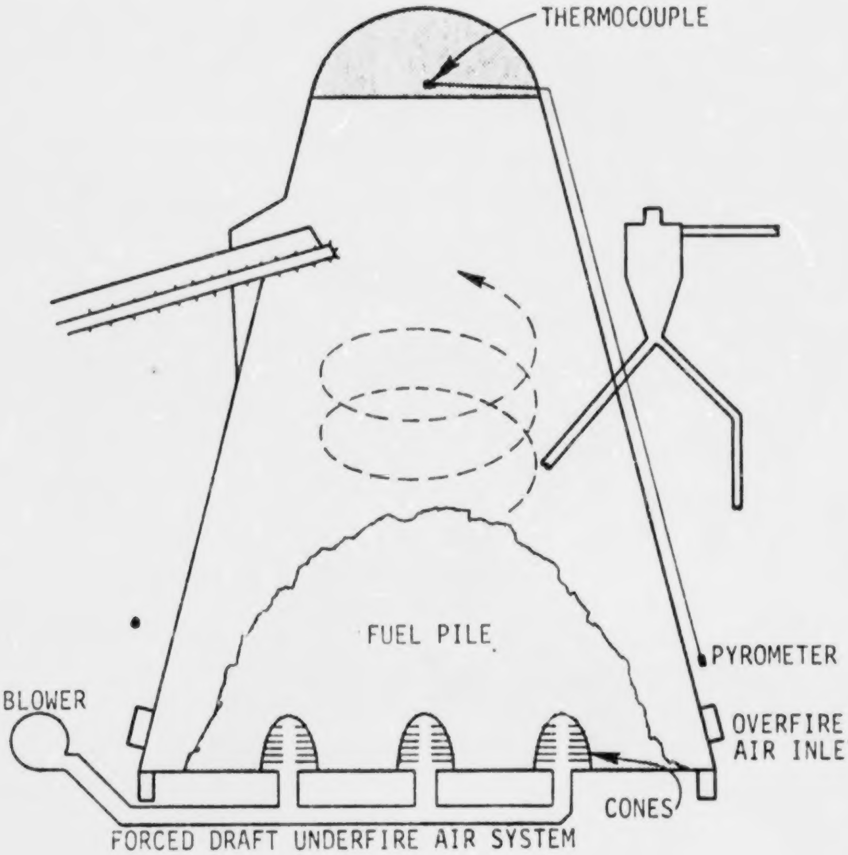
THERMOCOUPLE
FUEL PILE
PYROMETER
BLOWER
OVERFIRE AIR INLET
CONES
FORCED DRAFT UNDERFIRE AIR SYSTEM

Figure 2-1. Typical tepee waste burner.

Any CO generated burns above the pile.

Of course the ashes accumulate at the bottom and must be periodically removed to keep the forced-draft system operative.

It is apparent that once sufficient oxygen is supplied to complete the combustion, additional oxygen (and its associated nitrogen) will only tend to cool the reacting products and the exhaust gases. Air greater than theoretical is termed "excess air." Test data from several waste burners indicate that exhaust-gas temperatures may be related to excess air as shown in Figure 2-2. Because of this relationship a good indication of excess air may be obtained if the exhaust-gas temperature of the burner is known. The usual procedure for determining the amount of excess air from a combustion process is to take an exhaust-gas analysis, and from the fuel analysis and gas analysis calculate the excess air. For Douglas-fir such a calculation yields a curve as shown in Figure 2-3.

It has been generally found from field observations that if tepee burners can be operated so that the temperature of the gases leaving the top of the burner are greater than 600°F, emissions of smoke and other particulates will be minimized. A maximum temperature of 900°F is recommended, which leaves a satisfactory margin of safety before structural damage occurs. A summary of several field observations of smoke and exit-gas temperatures is shown in Figure 2-4.

WIGWAM BURNER DESIGN

The size of a burner required to consume a given quantity of waste is fairly critical. Too large a burner will operate at a low temperature and smoke severely,

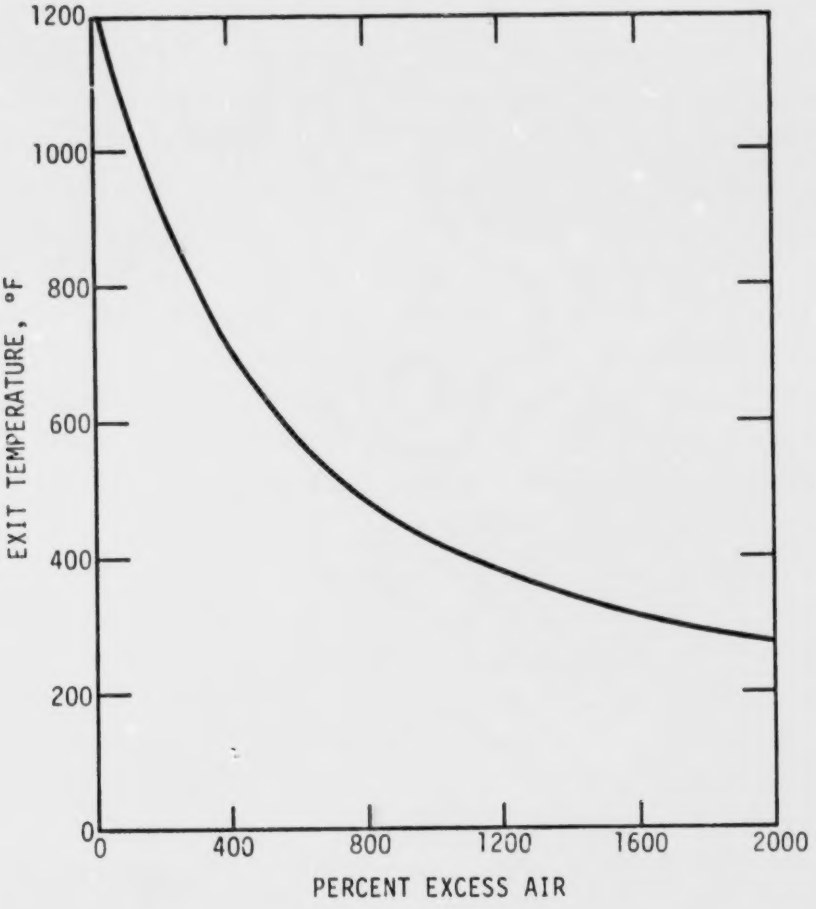

Figure 2-2. Correlation between temperature and excess air.[3]

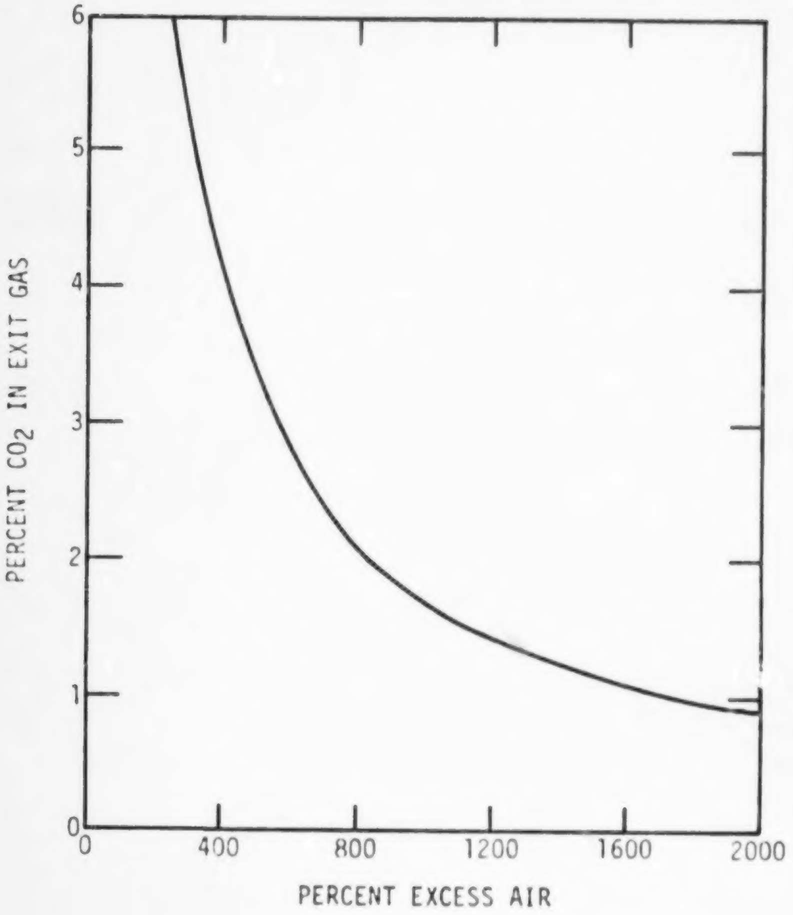

Figure 2-3. Correlation between CO_2 and excess air for Douglas-fir.[3]

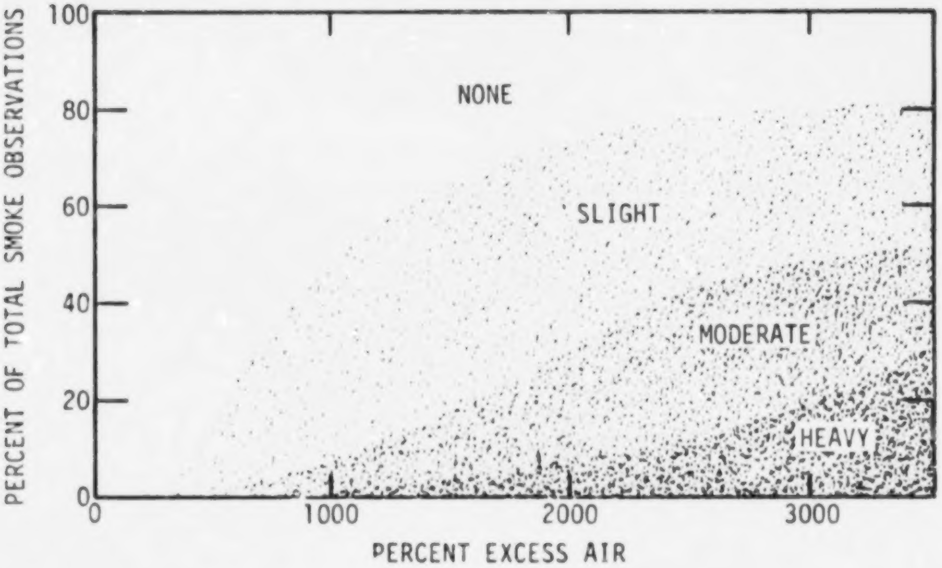

Figure 2-4. Relationship between smoke and excess air.[3]

while too small a burner will emit burning material. The correct size of a burner may be determined from the equation:

$$D = 2.3Q^{1/3} \qquad (1)$$

where;

D = diameter of base and height, ft
Q = quantity of waste burned, lb per hr.

Figure 2-5 is a graph of this sizing equation.

Example

An example of a typical burner design problem is the best way to illustrate the necessary calculations. For an example mill, assume the following as the necessary design factors:

Species - Douglas-fir (50% moisture and 50% dry wood)
Amount of Waste - 25,000 lb/hr (wet)
Desired Excess Air - 500% (which corresponds with 650°F exit-gas temperature)

Sizing - The sizing curve, Figure 2-5, indicates that for 12.5 tons per hour of wet fuel a 65-foot burner will be needed. The sizing equation verifies this:

$$\begin{aligned} D &= (2.3)\sqrt[3]{25{,}000} \\ &= (2.3)\ (29.25) \\ &= 67.2 \text{ ft} \end{aligned}$$

Air Supply - The air supply to the burner should be calculated so that sufficient forced-draft air is supplied to burn the fixed carbon. All other air, including the excess, should be supplied over the fire to burn the volatile gases and cool the exhaust products.

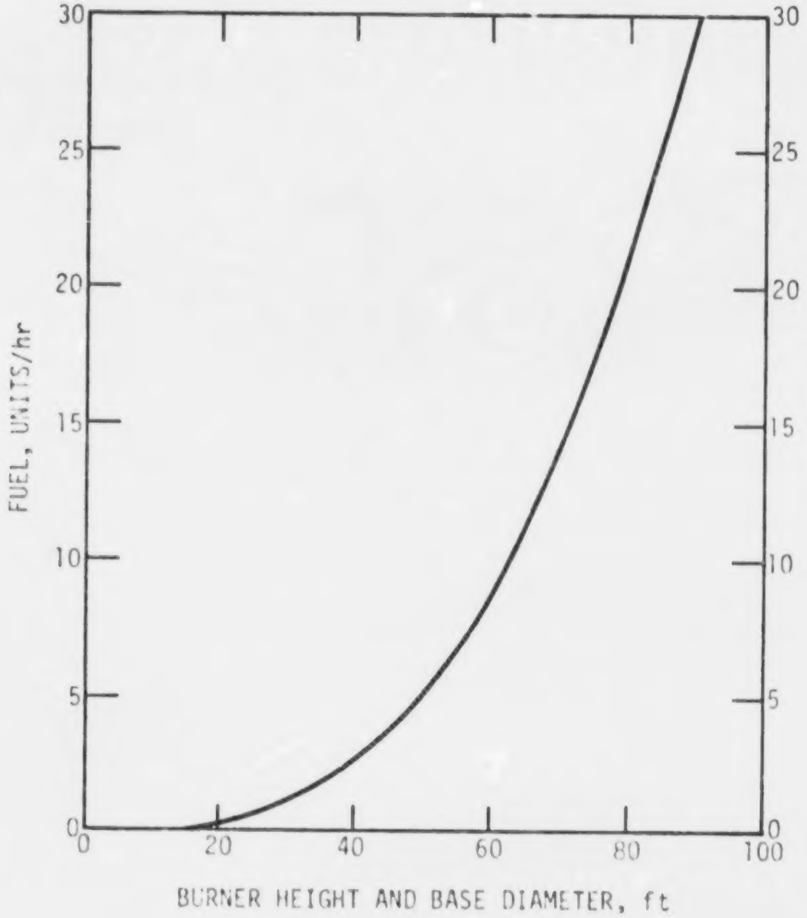

Figure 2-5. Burner sizing graph.[3]

Air for Forced Draft - Each pound of dry wood contains 0.17 pounds of fixed carbon: $C + O_2 \rightarrow CO_2$, so each 12 pounds of carbon requires 32 pounds of oxygen for complete combustion.

$$\frac{0.17 \text{ lb C}}{\text{lb fuel}} \times \frac{32 \text{ lb } O_2}{12 \text{ lb C}} \times \frac{100 \text{ lb air}}{23 \text{ lb } O_2} = \frac{1.97 \text{ lb air}}{\text{lb fuel}}$$

A 50 percent overload capacity for the forced-draft system should be provided, so:

$$(150\%)\ \frac{1.97 \text{ lb air}}{\text{lb fuel}} = \frac{2.95 \text{ lb air}}{\text{lb fuel}}$$

Calculating this volume at the fan:

$$\frac{2.95 \text{ lb air}}{\text{lb fuel}} \times \frac{\text{ft}^3 \text{ air}}{0.075 \text{ lb air}} \times \frac{12{,}500 \text{ lb dry fuel}}{\text{hr}} \times \frac{\text{hr}}{60 \text{ min}} = 8{,}200 \text{ cfm}$$

Air for Overfire - Carbon in volatile matter needs air:

$$C = \frac{0.52 \text{ lb C}}{\text{lb fuel}} - \frac{0.17 \text{ lb fixed C}}{\text{lb fuel}} = \frac{0.35 \text{ lb volatile C}}{\text{lb fuel}}$$

The theoretical air required is:

$$\frac{0.35 \text{ lb C}}{\text{lb fuel}} \times \frac{32 \text{ lb } O_2}{12 \text{ lb C}} \times \frac{100 \text{ lb air}}{23 \text{ lb } O_2} = \frac{4.06 \text{ lb air}}{\text{lb fuel}}$$

Hydrogen in volatile matter needs air. The theoretical air required is: $2H_2 + O_2 \rightarrow 2\ H_2O$, so each 4 pounds of hydrogen requires 32 pounds of oxygen for combustion.

$$\frac{0.06 \text{ lb } H_2}{\text{lb fuel}} \times \frac{32 \text{ lb } O_2}{4 \text{ lb } H_2} \times \frac{100 \text{ lb air}}{23 \text{ lb } O_2} = \frac{2.09 \text{ lb air}}{\text{lb fuel}}$$

The total overfire air for theoretical combustion is the amount for the carbon plus the amount for the hydrogen minus the amount which the oxygen in the fuel can supply. In other words, the air needed can be reduced by the amount of oxygen in the fuel plus the associated amount of nitrogen. The reduction in air because of oxygen in the fuel is:

$$\frac{0.405 \text{ lb } O_2}{\text{lb fuel}} \times \frac{100 \text{ lb air}}{23 \text{ lb } O_2} = \frac{1.76 \text{ lb air}}{\text{lb fuel}}$$

Theoretical overfire air is therefore:

Air for C + Air for H_2 - Air replaced by O_2 =

$$\frac{4.06 \text{ lb air}}{\text{lb fuel}} + \frac{2.09 \text{ lb air}}{\text{lb fuel}} - \frac{1.76 \text{ lb air}}{\text{lb fuel}} = \frac{4.39 \text{ lb air}}{\text{lb fuel}}$$

Five hundred percent excess air means that we must supply six times the theoretical so:

$$\text{Overfire air} = (6)\ \frac{4.39 \text{ lb air}}{\text{lb fuel}} = \frac{26.34 \text{ lb air}}{\text{lb fuel}}$$

The volume of overfire air is:

$$\frac{26.34 \text{ lb air}}{\text{lb fuel}} \times \frac{\text{ft}^3 \text{ air}}{0.075 \text{ lb air}} \times \frac{12{,}500 \text{ lb dry fuel}}{\text{hr}} \times \frac{\text{hr}}{60 \text{ min}} = 73{,}170 \text{ cfm}$$

To size the overfier-air openings, the draft must be calculated. At 650°F the exit gases have a weight compared to the surrounding air of:

$$\frac{70 + 460}{650 + 460} \quad \text{or} \quad 47.7\%$$

In a 65-foot burner the draft produced would be:

$$(1.000 - 0.477)\ 65 \text{ ft} = 34 \text{ ft of air}$$

(A draft gauge at the base of the burner would read this as about 1/2 inch of water.)

The velocity through the overfire-air openings produced by this draft would be:

$$V = \sqrt{2gh} = \sqrt{(64.4)\ \frac{\text{ft}}{\text{sec}^2} \times 34 \text{ ft}} = 46.8 \text{ fps}$$

The area of the overfire-air openings would be:

$$A = \frac{Q}{V} = \frac{73{,}170 \text{ ft}^3}{\text{min}} \times \frac{\text{sec}}{46.8 \text{ ft}} \times \frac{\text{min}}{60 \text{ sec}} = 26 \text{ ft}^2$$

Assuming a 50 percent oversize to take care of any overload, the overfire-air openings would have to have a combined volume of 39 ft^2. This could be accomplished, for example, by using ten 2-foot by 2-foot openings.

The overfire-air openings should be of the tangential type, with dampers for the control of the air volume passing through them. The damper design should be such that it does not interfere with the cyclonic action induced by the tangential openings when the dampers are partially closed.[4]

The air supply for the burner would be 8,200 cfm forced draft, or underfire air, and 73,170 cfm overfire. This breaks down to a total of 81,370 cfm of which 10 percent is supplied by the forced-draft system. Two 15-horsepower centrifugal fans would adequately supply the forced-draft requirements.

Propeller fans are not recommended for forced-draft systems on waste burners. Propeller fans are designed for high-volume flows at low-static pressures, and the forced-draft system will be easily plugged if they are used.

WIGWAM BURNER CONSTRUCTION

General

Most construction details have been standardized by the industry. A review of some, however, seems appropriate. All structural members should be external to the shell. This will enable them to carry the load and be shielded from the heat within the burner. Some builders are using annular trusses, particularly at the top of the burner. At high operating temperatures the truss is not weakened and satisfactorily supports the shell plates.

Adequate doors and other provisions must be made for cleaning the burner. Doors should be sized so that a loader, or similar vehicle, can enter the burner. The forced-draft system must be designed to carry the weight of the loader. If projections, such as cones or elbows, are used in the forced-draft system, they should be removable or protected during the cleaning operation.

The fuel should be admitted as low in the burner as possible. This can be aided by using water-cooled conveyor bearings which allow for an overhang of the conveyor system. Discharge pipes from air-cyclone conveying systems should deposit their planer shavings, sawdust, etc., as low as possible to permit combustion of these small bits of fuel rather than entrainment in the exit gases.

Draft Systems

The forced-draft system should be designed to give an even air distribution throughout the entire fuel pile. A satisfactory system consists of one or more blowers ducted to the grates in the burner floor. The grates may be flat grids or plates with perforations, conical (bee-hive) type grates, or elbows or discharge boxes designed to impart a tangential flow to the inlet air if they become uncovered. All of the forementioned grate types have operated satisfactorily when properly sized.

Dampers should be provided in the forced-draft system to throttle the flow of air under startup and light load conditions. These may be either at the fan inlet or outlet, but they should be equipped with some type of position indicator so that settings may be consistent once proper operation is established.

The overfire-air system should contain suitable dampers at each port. Barometric dampers have been used, but they require delicate adjustments which tend to change as the bearings and shafts weather and corrode. Most satisfactory systems are manually adjustable with the ports and dampers arranged so that they are not damaged by falling slabs. edgings, or other fuel.

Thermocouple

A very necessary and inexpensive part of the waste burner is a thermocouple installed at the top to indicate exit-gas temperature. This permits a burner to be operated at optimum conditions for disposal of waste with a minimum of atmospheric pollution. Figure 2-6 shows a very satisfactory arrangement for such a thermocouple system which can be installed for less than $500. The thermocouple is relatively trouble free and with normal maintenance will outlast the burner itself.

NOTE: PYROMETER INSTALLED IN WEATHERPROOF HOUSING FURNISHED BY OWNER. LOCATE AT EYE LEVEL (APPROX. 5 ft) AT LEAST 15 ft. FROM BURNER SHELL.

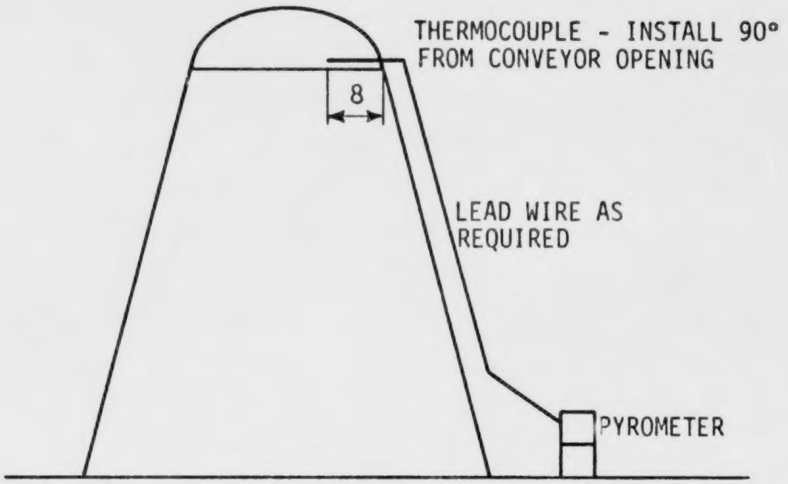
THERMOCOUPLE - INSTALL 90° FROM CONVEYOR OPENING
8
LEAD WIRE AS REQUIRED
PYROMETER

Figure 2-6. Installation drawing; thermocouple with indicating pyrometer.

3. WIGWAM BURNER OPERATION

The correct firing of a tepee burner becomes both an art and a science. A properly operated burner will dispose of the residue with a minimum of smoke and other pollutants. A poorly fired burner will smoke and deposit particulate over a wide area even though it may be properly sized and designed. One of the most common mistakes is to fire the burner with the access door open. This severely upsets the draft balance and air distribution in a properly designed burner. The fire may appear to burn more rapidly for a short period of time because the fuel pile glows more. This is due to the increased "forge effect" on the fixed carbon. Fixed carbon is only about one-seventh of the fuel by weight. Firing with the door open, in order to get apparently better combustion for a relatively small percentage of the fuel, actually chills the volatile gases and hinders their combustion. If the forced-draft system was adequate and properly operated in the first place, opening the door would not aid the combustion of the fixed carbon. An open access door on an operating tepee burner is a glaring indication that something is improper with the design, loading, or operation of the burner.

OPERATING LOG

A written log is necessary for proper burner operation. Only if entries concerning draft settings, gas temperature, smoke, fuel, etc., are faithfully made will the operator know the optimum firing situation. If it is noted in the log that a certain series of settings gave smokeless operation for a particular fuel load and type, then the settings can be used for future firings. If no written record is available, the proper settings are quickly forgotten. A suggested form for the written log is given on the following page.[3] It can be modified for any particular burner or mill.

STARTUP

Probably the most difficult period of burner operation is during the startup. The residue starts coming from the mill and the burner is expected to handle it. Unless the burner is previously heated and contains a good fire, this fresh residue will tend to extinguish the fire rather than increase the rate of combustion.

An adequate fire must be started in the burner well before the first residue is sent to it. An hour before the start of production is a good time to get the burner operating. Dry planer ends, slabs, edgings, etc., should be accumulated from the previous day's operation and available to build a satisfactory fire in the burner. The fire should be built and started with the overfire-draft doors closed and the underfire air set very low. A good-sized preliminary fire should be the goal by startup time of the mill. Once the residue starts entering the burner from the mill, the fire will sustain itself only if proper control of the air supply is exercised. The general tendency is toward too much overfire air, which only tends to excessively chill the fresh fuel. Cold air does a poor job of drying wood fuel. The overfire air should be kept from the fire

BURNER LOG

Date____________________
Name of Co.____________________
Address____________________
Burner size____________________

Operator____________________
Est. hourly production____________________
Est. hourly waste to burner____________________
Species and type of waste____________________

Time	Overfire draft setting	Forced draft setting	Exit gas temp.	Smoke density and color	Fallout emission	Weather	Wind direction and velocity	Auxiliary fuel used	Remarks

Figure 3-1. Format for burner operating log.[3]

until the fire is self-sustaining, and then the draft settings may be opened to their normal operating positions.

Many state and regional air pollution control agencies have recognized that wigwam burners will smoke so much during the startup period that they cannot meet opacity regulations. To permit the burners to operate most regulations are written with a clause allowing a deviation from opacity standards for the first 1/2 hour or hour of burner operation. If only 1/2 hour is allowed the operator must build an extremely hot fire before the normal fuel flow starts. This is usually done using dry wood plus an auxiliary fuel such as gas or diesel oil. If one hour is allowed for startup it is usually possible to get an adequate fire established using only dry wood at startup.*

FUEL CHARGING

Combustion is properly established when the fuel is consumed at the same rate it enters the burner. The operator should adjust the burner so that the exit-gas temperature is between 600°F and 900°F and smoke and particulate are at a minimum. A good clue to overall burner operation is smoke. Since smoke is particulate, it indicates how well the fire is consuming the residue material. With "no smoke" you can be sure that the burner is doing its best job and that a minimum of pollutants and particulate are leaving the top of the burner.

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* Actual regulations and startup times should be obtained from the appropriate State Implementation Plan (SIP) covering the specific burner.

Slight adjustments in burner operation may have to be made even during periods of apparently continuous operation. Waste quantities will vary or even stop completely during breaks and lunch hour. Weather or wind changes will affect the combustion. The fireman should be continually aware of the situation and make small corrections to the draft settings as required.

SHUTDOWN

Another critical period in burner operation is when production stops for the day. If the burner has been properly operated, only a normal fuel pile will exist inside. About one half hour after the mill stops this will be reduced to practically 100 percent fixed carbon, and the overfire draft doors should be closed. Only after the fixed carbon has been consumed may the forced-draft blowers be shut off.

If the burner was not operating properly during the period of mill production, an extremely large fuel pile may have accumulated by the end of the working day. A fireman must remain in attendance at the burner until this large pile is consumed. Many burners have been badly damaged because a large fuel pile fell against the side of the burner and the excessive heat and lack of cooling buckled the structure and shell.

CLEANING AND MAINTENANCE

Care of the burner is another important factor for proper firing with a minimum of pollution. The burner should be completely cleaned of ashes at least once a week. A thorough inspection should accompany this cleaning and any faults or defects reported to the millwright or maintenance superintendent. Leaks in the shell and warped doors are more easily spotted from inside the burner than from outside. If repairs are needed, they should be made immediately to put the burner back into proper operating condition. Remember that the burner costs the mill owners somewhere around $10,000 per year. It deserves to be treated with care.

4. ATMOSPHERIC EMISSIONS FROM WIGWAM BURNERS

REGULATIONS

Regulations covering emissions from wigwam burners are concerned with only particulate matter and/or visual emissions. No regulations are known which apply to gaseous pollutant emissions from wigwam burners. Some states and regions have design and construction standards which apply.

Regulations for Particulate Emissions

Particulate regulations can be expressed in several ways:

1. Mass emission per cubic volume of exhaust gas, usually normalized at 12% CO_2 to account for dilution by excess air. Many agencies have adopted a regulation of 0.2 grains per standard cubic foot of gas corrected to 12% CO_2 for existing burners and 0.1 grains per standard cubic foot of gas corrected to 12% CO_2 for new construction of burners after a certain date. Some of the regulations state that the standard cubic foot is "dry", meaning the water volume present in the gas phase must be subtracted. Other regulations may not state whether the cubic foot is wet or dry. The "standard" cubic foot may also be ambiguous. The "standard" temperature for a cubic foot depends upon regulation and may be 32°F, 60°F, 68°F, 70°F, or 20°C, which is equivalent to 68°F. The "standard" pressure for the same cubic foot may

be expressed as 29.92 inches of mercury which is the same as 14.7 pounds per square inch or one atmosphere. Some agencies, however, use 30.00 inches of mercury for the standard cubic foot.

2. Mass emission per unit of energy input to overcome the problems of defining the standard cubic foot. The usual emission standard is 0.1 pounds of particulate per million BTU of input energy. Some agencies may allow a higher value (0.2 pounds per million BTU) for burners existing before a certain date.

3. Mass emission per unit of process weight, usually included with the allowable mass emission for the entire mill. If a process weight chart (such as the Bay Area APCD chart) shows an allowable atmospheric discharge the wigwam emission is included along with emissions from cyclones, driers, etc., to determine the total. If the wigwam burner is the only source at the mill it can emit particulate up to the maximum allowed by the process weight chart and still be legal.

Regulation of wigwam burners by means of visual emission standards usually refers to the opacity of the effluent from the burner. A certified observer must read the opacity periodically and determine if the burner is in compliance or not. Typical regulations may state, "No visual emissions exceeding 10% opacity will be permitted except for 3 minutes in any one hour." Some agencies will use 20% opacity for existing burners and 10% opacity for new burners. The time exemption may be differently stated in the regulations to clarify it or further define it.

The observer making the opacity readings must be trained and certified by the control agency. He must be aware that opacity readings can be affected by such things as stack exit diameter, moisture content of the plume, particulate size, particulate shape and color, background lighting and textures, sun position and angle, sky color, etc.

The Oregon State Sanitary Authority* was one control agency which chose to adopt Construction and Operation Standards rather than emission standards (Appendix A). These standards, adopted in 1965, are typical of similar standards adopted by other agencies.

THEORETICAL EMISSIONS

Particulate Emissions

The particulate emissions from a wigwam waste burner may be theoretically approximated. The example problem used earlier will be used for calculation purposes:

Fuel - Douglas Fir; 50% moisture, 0.8% ash
12,500 pounds of dry fuel per hour,
Heating Value 9,050 BTU per dry pound.
Excess Air - 500% for 650°F exit temp.

The air supply was calculated at 81,370 standard cfm total which yields exhaust gas of 27.34 pounds per pound of fuel. If we assume that one pound of exhaust gas occupies the same volume as one pound of standard air, we can calculate the following value:

$$\text{scfm of exhaust gas} = \frac{27.34 \text{ lb gas/lb fuel}}{26.34 \text{ lb air/lb fuel}} (81{,}370 \text{ cfm}) = 84{,}460 \text{ cfn}$$

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* Presently the Oregon State Department of Environmental Quality.

Assuming that one half the ash in the fuel goes out the top of the burner as fly-ash and that the fly-ash is usually 50% ash and 50% unburned carbon:

$$\text{particulate emission} = (12{,}500 \text{ lb fuel/hr})\left(\frac{.008 \text{ lb ash}}{\text{lb fuel}}\right)\left(\frac{1 \text{ lb partic.}}{1 \text{ lb ash}}\right) = 100 \text{ pounds per hour.}$$

On a basis of mass emission per energy input:

$$\left(\frac{100 \text{ lb. partic.}}{\text{hour}}\right)\left(\frac{\text{hour}}{12{,}500 \text{ lb fuel}}\right)\left(\frac{\text{lb fuel}}{9050 \text{ BTU}}\right) = 0.88 \text{ pounds per million BTU}$$

Or on a basis of grain loading:

$$\left(\frac{100 \text{ lb partic.}}{\text{hour}}\right)\left(\frac{7000 \text{ grain}}{\text{pound}}\right)\left(\frac{\text{min}}{84{,}460 \text{ ft}^3}\right)\left(\frac{\text{hour}}{60 \text{ min.}}\right) =$$

0.138 grains per scf (not corrected)

Since 500% excess air corresponds with 3 1/2% CO_2, the corrected grain loading is:

$$\left(\frac{0.138 \text{ grains}}{\text{ft}^3}\right)\left(\frac{12.0}{3.5}\right) = 0.473 \text{ grains per standard cubic foot corrected to 12\% } CO_2$$

From the previous theoretical calculations it becomes quite obvious that in order to meet an emission standard of either 0.1 pounds per million BTU of input or 0.1 grains per standard cubic foot corrected to 12% CO_2, some control must be considered.

MEASURED EMISSIONS

Particulate Emissions

Actual emissions from wigwam burners have been found to be of the same order of magnitude as the previously calculated theoretical emissions. On a well designed and operated burner, firing a clean fuel at a rate high enough to operate in the 600°F to 900°F range, the actual emissions may be as low as 0.1 grains per standard cubic foot corrected to 12% CO_2. On a poorly maintained burner, firing a finely divided and dirty fuel (such as bark coated with soil), at a low or intermittent fuel feeding rate, the actual emissions may be greater than 1.0 grains per standard cubic foot corrected to 12% CO_2.

Tests of 100 samples from 19 different wigwam burners in Oregon, taken in 1968, are summarized in Table 4-1.[5]

The average emission temperature was 485°F which is considerably below the 600°F - 900°F temperature range recommended for smoke-free operation.

The average loading to the atmosphere was 0.168 grains per cubic foot of gas corrected to 12% CO_2 and standard temperature (60°F) and pressure (30.00 inches of mercury). This value is considerably below the value used by many control agencies of 0.2 grains per cubic foot for allowable incinerator emissions. Converted to metric units, the average particulate emission is 384 mg/m^3 (corrected to 12% CO_2 and STP). If the air/fuel ratio for a typical wood is assumed (12% CO_2 is approximately equivalent to 9.5 pounds of air per pound of fuel) the average emission can be calculated as 10.7 pounds of particulate per ton of fuel consumed. Possibly it would be easier to remember, as well as being simpler, if it were rounded to 11 pounds per ton.

Table 4-1. PARTICULATE EMISSIONS FROM 19 WIGWAM WASTE BURNERS IN OREGON, 1968[5]

Burner number	Average gas temp, ° F	Particulate emissions, grain/ft^3
1	389	0.171
2	539	0.105
3	400	0.080
4	455	0.120
5	291	0.312
6	544	0.155
7	525	0.129
8	598	0.224
9	866	0.130
10	435	0.284
11	405	0.191
12	379	0.163
13	338	0.252
14	208	0.194
15	166	0.132
16	519	0.021
17	791	0.128
18	230	0.160
19	308	0.252
Overall average	485	0.168

Two distinct size distributions were noted upon microscopic examination of the collected material. One size distribution was noted for a larger particulate which was capable of settling to the ground as dustfall. Another distribution was noted for the smaller sized particles which are seen as "smoke" and are referred to as suspended particulate. An average value of about one quarter of the mass of the particulate would be considered as "smoke" or suspended particulate.

A correlation matrix of variables was run to see if there was a significant relationship between variables measured during this study. Only three significant correlations were found but they were very interesting as they indicate how a burner might be operated to reduce air pollution:

1. The particulate emission correlates inversely with the emission temperature, i.e., the higher the temperature, the lower the emissions.
2. The draft ratio (actual/theoretical) correlates directly with temperature. High temperatures, and hence lower emissions, are achieved with a tighter burner (better maintenance and the doors closed).
3. The percent of ash in emissions correlates directly with temperature. Higher emission temperature indicates more complete combustion with less material to be emitted as an air pollutant.

The size of the particulate emitted did not correlate significantly with temperature which would indicate that it was more a function of the material being fed to the burner than how the burner was operated.

Gaseous Emissions

Although generally not mentioned in the emission standards, the gaseous pollutants from a wigwam burner are significant, greatly exceeding particulate emissions.[6] One study from California during the mid 1960's reported extensive gaseous pollutant analyses which are summarized in Table 4-2.[7]

The gaseous emissions show the same inverse correlation with temperature as noted for particulate emissions. The higher the operating temperature, the lower the gaseous emissions.

Table 4-2. AVERAGE GASEOUS EMISSIONS FROM WIGWAM BURNERS[7]

Shell temp, range,[a] °F	Average pounds of gaseous pollutant per ton of wood residue burned		
	CO	Total hydrocarbon	C_2 + hydrocarbon
90 - 150	189	17.5	7.2
160 - 200	176	15.0	4.5
210 - 250	144	10.6	4.7
260 - 300	125	13.8	5.5
310 - 350	78	4.5	1.7
410 - 450	62	1.4	0.8

[a] Shell temperatures are approximately 1/2 of exit gas temperatures, °F.

Oxides of nitrogen from wigwam burners are not considered a serious problem because of the low combustion temperatures involved. It is generally assumed that oxide of nitrogen emissions are "negligible", even when exit gas temperatures reach values as high as 900°F.

OPACITY

One would expect opacity to be directly correlated with particulate emissions. This is true, so whatever affects particulate emissions will also affect opacity. Opacity may also be related to other variables of firing conditions or ambient weather conditions. When firing wet fuel, for example, as long as the exit gas temperature is below the dew point, a visible plume will persist due to the condensing water vapor. Above the exit gas dew point temperature, the opacity may be expected to vary as particulate emissions.

(This may not always be true as some studies show poor correlation over about 70% relative humidity).

The opacity of the plume of course relates to the size, shape, and color as well as the mass of the particulate. A burner emitting 0.1 grains per standard cubic foot with a size distribution of 0.1 - 0.5 micrometers would have a high opacity plume while one emitting 1.0 grains per standard cubic foot with a size distribution of 2.0 - 20.0 micrometers would show a nearly clear plume.

In general, the information in Table 4-3 is a good rule of thumb for wood burning combustion sources, including wigwam burners. It should be noted that Table 4-3 relates to about 50 - 150% excess air so the values of opacity read from a wigwam burner at higher excess air values should be lowered accordingly.

Table 4-3. APPROXIMATE EQUIVALENT VALUES OF OPACITY AND GRAIN LOADING FOR WOOD FIRED COMBUSTION SOURCES

Grains per SCF	Opacity, %
0.00	0
0.10	10
0.20	20
0.50	50

Figure 2-4, shown earlier in this report, is developed from data obtained from over 200 waste burner tests.[1,2] The equivalent opacity values corresponding to the descriptive terms used in this figure are shown in Table 4-4 which summarizes Figure 2-4.

Table 4-4. RELATIONSHIP BETWEEN OPACITY AND OPERATING PARAMETERS OF A WIGWAM BURNER[1,2]

Smoke description as per Fig. 2-4.	Opacity range, %	Percent of total smoke observations in specific smoke & opacity ranges					
		250% x's air 850°F	500% x's air 675°F	750% x's air 500°F	1000% x's air 430°F	1500% x's air 325°F	2000% x's air 270°F
None	0-25	100	81	65	52	36	25
Slight	25-50	0	18	30	40	46	43
Moderate	50-75	0	1	4	6	14	24
Heavy	75-100	0	0	1	2	4	8

OPERATION TO MINIMIZE EMISSIONS

Combustion Control

The previous data, tables, and figures indicate that all emissions, visual, gaseous, and particulate, decrease as combustion improves within the burner. The exit gas temperature is probably the best single indicator of combustion conditions and may therefore be relied on as the variable of interest to the operator. If an operator is familiar with the combustion characteristics of a given burner, he can use this information to minimize the atmospheric emissions. Suppose, for example, a certain wood waste burner log shows that an exit temperature of 600°F and above results in a clear plume when burning hemlock trim and bark. If the exit gas temperature is only 400°F with this fuel, and the burner is smoking, the operator should cut back on his air or increase the fuel to get to the higher temperature. Since the fuel feeding rate is usually fixed, the operator will most likely adjust the air supply.

If on the same fuel the exit gas temperature is 900°F and the operator is concerned about the structural members should the temperature increase, he can increase the airflow to the burner. He knows he can drop the exit gas temperature to as low as 600°F without increasing particulate or opacity appreciably.

The State of Oregon, Department of Environmental Quality, has determined that minimum emissions from a wigwam burner will be obtained if the following conditions are satisfied: [4]

a. That the waste burner size be compatible with the fuel load.

b. That fuel be correctly introduced at a reasonably uniform rate and be of such physical characteristics as not to obstruct passage of underfire air or combustion gases from the heat release within the fuel pile.

c. That an adequately designed underfire air system be provided. Such a system must be adjustable, or sufficient capacity for the maximum rate of fuel supply, and must introduce air with sufficient dispersion to preclude "channeling" through the fuel pile.

d. That adjustable, tangential overfire ports be provided of ample capacity to supply at least 10 times the underfire air volume at a differential pressure corresponding to the burner stack effect at 300°F exit and 90°F ambient temperatures.

e. That the burner shell be reasonably airtight to preclude parasitic leakage and thus cooling effect and lack of control of overfire air.

f. That adequate maintenance practices be observed to assure optimum performance of the underfire air system at all times.

g. That operational practices include frequent adjustment of underfire air volume (firing rate) and overfire air volume as required to maintain optimum exit temperature at all times.

It may be generally stated that if a wigwam burner is smoking it needs less excess air to eliminate the smoke. Opening an access door, for example, lets in more cold air which may momentarily cause an apparent increase in the combustion rate but immediately starts to chill the entire fire. Only in the rare case where exit gas temperature is in the range above 900°F and the burner starts emitting dense black smoke (indicating unburned carbon) is it necessary to increase the airflow to get rid of the smoke.

Ash Removal

The burner must be kept free of excessive ash buildup and in good repair. The fans and grate system must be inspected periodically to assure they are operating at peak efficiency. If a handful of sawdust is thrown into a fan inlet, and it is not sucked into and through the fan, it indicates that the system is plugged and needs immediate attention.

5. WIGWAM BURNER MODIFICATIONS

When one looks at the simple wigwam burner with its natural draft overfire air supply, uncontrolled forced draft air, and variable fuel feed it becomes apparent that modifications could be made to improve combustion. All of the following suggestions for modification have been tried at one time or another, either singly or in combination.

PHYSICAL MODIFICATIONS

Sizing

Many mills are faced with the situation of having a wigwam burner too large for disposal of their available residue. The wigwam may have been originally sized to handle all of the waste and now part of the material is being utilized and only a portion is being incinerated. In this case it may be desirable for the mill to construct a smaller, properly sized burner for optimum disposal of the residue with a minimum of pollution.

In the case where too much fuel is available for the burner the obvious solution of going to a larger, properly sized burner should be considered.

In either case, where a new burner of the proper size is indicated, other modifications listed in this report should be considered. It is much easier, and less expensive, to include the necessary modifications when the new burner is designed and constructed rather than trying to retrofit an existing burner.

Dampers

Dampers allow the flow of gas or air to be restricted. Dampers in wigwam burners may be installed in three separate places to adjust the air or gas flow:

1. In the top of the burner just below the horizontal screen. This decreases the gas volume leaving the burner and allows the combustible material to remain in the burner longer. The overall effect of this damper is the same as going to a smaller burner, when it is partially closed. For light fuel loading the damper may be nearly closed and yet it can be opened for heavy fuel loadings.
2. Individual dampers at each overfire air port. These may be closed to restrict the overfire air flow during times of startup or light fuel feeding. They may be opened as necessary as the fuel loading increases. Control with these dampers will be indicated as a change in the exit gas temperature indicated by the thermocouple. If the exit temperature is too low the dampers should be closed to cut back on the cold air entering the burner. If too hot, the dampers should be opened.
3. Dampers in the forced draft system may be either ahead of or after the forced draft fan. They should be adjusted to give less air flow during startup or with light fuel loading. When the burner is operating near design capacity they should be fully opened to allow proper air through the grates. Caution should be exercised in design of these dampers that they be not completely closed. Some air flow must be kept through the grates to cool them.

FUEL MODIFICATIONS

Fuel Introduction

The ideal way to introduce the fuel would be to mix all the residue in an external fuel house and then feed the burner at a constant rate. This would result in a uniform fuel as far as both quality and quantity. Constant fuel feed would simplify the burner operation as it could be set for the constant fuel flow and then left unattended unless an upset occurred.

Another alternative is to fire the burner so that some fuel is entering at all times and there are no periods without fuel. For example, if a burner is being operated on a mixture of bark and sawdust have the barker crew take their lunch break at a different time than the sawmill crew. This would assure at least partial fuel feed without the normal, complete interruption during lunch.

The fuel mixture is important to the combustion within the burner. If, for example, sawdust falls on one side of the burning pile and trim ends and edgings fall on the other, the sawdust may smolder due to packing too tightly while the other half of the pile burns properly. By mixing the fuel external to the burner, on conveyors or other handling systems, the fuels can complement each others' characteristics. Dry sander dust mixed with wet bark will make an excellent fuel. If they were fired separately in the same burner we might expect problems.

If light fuels such as sander dust, planer shavings, or sawdust are to be introduced directly to the burner from the discharge of a cyclone, they should be introduced as low as possible. This will enable them to remain in the combustion zone longer before being carried to the top of the burner.

Auxiliary Fuel Systems

If a burner cannot reach proper operating temperature an auxiliary fuel system may be considered. Natural gas or propane is the most commonly used auxiliary fuel although diesel oil is sometimes used. The auxiliary fuel is fired in long-flame burners pointing at the top of the fuel pile. For startup, or low temperature conditions, the auxiliary burners are ignited and kept in operation until the waste fuel can maintain the desired exit gas temperature. The auxiliary burners may be mounted on wheels or tracks to allow their removal from the burner once the fire is established. Some wigwam burners firing very wet fuel use as many as 3 auxiliary burners to get the fire started in the morning and then leave one burner operating continuously throughout the shift.

AIR SYSTEMS MODIFICATIONS

Overfire Air Systems

The overfire air system on many wigwam burners consists simply of openings in the shell, a foot or two above the base. Construction of ducts at the openings to cause a tangential flow of the overfire air inside the burner is an improvement. This allows the lighter fuel particles to remain in the combustion zone longer. Dampers can be fitted to the overfire air openings so that the airflow to the burner may be regulated.

On some burners the overfire air openings are replaced with an overfire air fan and manifold around the burner. The airflow to the burner may then be easily controlled by a single damper at either the fan inlet or outlet. The ultimate modification to the overfire air system is an automatic fan control using a modulating damper on the fan inlet. As the exit gas temperature increases above a certain set point, the damper opens to admit more overfire air. Should the exit gas temperature decrease below a certain value the damper closes and the excess air decreases thereby raising the temperature.

Underfire Air Systems

Modifications to underfire air systems are generally directed toward rebuilding the grate system to give more uniform air flow with fewer blow holes and adding dampers to control the total air flow. Many of the existing underfire air systems are inadequate for their operating conditions. Fans may be of the propeller type which do not develop enough static pressure to keep the air flowing through the fuel pile.

Changes in fuel, since the burner was originally designed, may be plugging the grates. Sawdust is a material which will plug many grate types and is best burned in a burner with elbow or conical grates.

SYSTEMS MONITORING AND OPERATING MODIFICATIONS

Instrumentation

Instrumentation that may be added to a burner to aid in proper combustion with a minimum of air pollution is similar to that used on other combustion systems. The previously mentioned thermocouple and pyrometer system is the minimum that should be considered. At the other extreme would be a fully instrumented burner with oxygen or CO_2

recorder, draft guages for overfire and underfire systems, damper position indicators, and possibly even an opacity monitoring instrument at the burner exit.

A further modification would be to take one or more of the instrument output signals and utilize these directly or through a computer to control an appropriate system on the burner. The ultimate system would be a completely computer controlled system using exit temperature, draft gauge readings, gas analysis data, and outlet gas opacity readings to adjust the burner for optimum combustion with minimum opacity or particulate emissions.

Any instrumentation should be installed in weatherproof cabinets and shielded from the extreme temperature near the burner shell. Recording instruments are preferable to indicating only instruments because they yield a permanent record which may be used for optimizing the burning process.

Maintenance and Operation

The burner may have to be modified to permit satisfactory maintenance. The door must be large enough to get a vehicle inside to clean out ashes. The grate system must be strong enough to support the vehicle or have removable elbows, boxes, or cones to allow complete ash removal.

A complete maintenance schedule for the burner should be adhered to. Of course, a fully modified burner with auxiliary burners, installation, and controls will require more maintenance than one that is only the simple wigwam burner.

Operation of the burner should be assigned to a person knowledgable about combustion. To properly fire a wigwam burner requires as much skill as to properly fire a boiler. Unfortunately, the job of firing the burner is usually detailed to someone who does not really understand combustion reactions in wigwam burners.

GAS CLEANING EQUIPMENT

Wigwam burners do not really lend themselves to installation of gas cleaning equipment. Scrubber installations have been used with moderate success. Usually, the visible, condensing water plume from the scrubber is more objectionable to the population than the clear to slightly opaque plume from a properly operated burner. Since the cost of the scrubber approximately equals the cost of a fully modified, new wigwam burner it appears to be a rather poor investment.

The tremendous volumes of hot gases leaving the wigwam, at near atmospheric pressure, result in large and expensive gas cleaning devices with large, high horsepower fan requirements. Also, the particulate emitted from the burner may cover a size range from sub-micron (smoke) to millimeter-plus material (cinders or partially burned fuel). For such a wide variation of particle sizes it is probable that no one single piece of control equipment could do a satisfactory job. Double or higher costs are necessary for multiple control devices in series.

OTHER MODIFICATIONS

The modifications mentioned previously are those considered as being practical with some real benefit. Several other modifications have been suggested over the years and some of them tried on various burners. The following modifications fall into this category and are listed here to indicate that they have been considered and then rejected as being unpractical.

Fuel Drying Systems

Fuel drying systems enable combustion of excessively wet fuels. This would be extremely expensive and would only accomplish the drying of the fuel external to the burner rather than within the burner. Condensation problems in the ductwork might be severe.

Preheating Combustion Air

Preheating of combustion air is achieved by recirculating hot gas from the top of the burner. To do any kind of proper heating would require effective insulation of ducts to prevent condensation. The costs would far exceed the small benefits gained.

Sprinklers for Cinder Control

Lawn sprinklers on top of the burner do nothing to control emissions. They may wet down the area downwind and prevent fires from a poorly operating burner that is discharging burning cinders.

Refractory Linings

Refractory linings are installed either in the lower portion only or all the way to the top. These refractory linings are very expensive and need continual maintenance. They are subject to damage by falling material and during clean-out. A properly designed and operated burner will burn just as clean without refractory as it will with refractory.

Natural gas or propane mixed with the underfire air

This mixture does not burn until it has passed through the fuel pile. It then burns with less effectiveness than if it had been fired in auxiliary burners. Explosion hazards also should be considered.

COSTS AND SCHEDULES FOR MODIFICATIONS

The capital costs, yearly operating costs (including maintenance) and time schedules for the wigwam burner modifications discussed are shown in Table 5-1. The costs are approximate for today (1975) and should of course be verified. The same applies to stated delivery schedules.

Several burner manufacturers are presently constructing and modifying burners as mentioned in this report. A few of these are:

1) Rees Burner Company, Memphis, Tennessee
2) Medford Steel and Blowpipe Co., Medford, Oregon
3) Steelcraft Corporation, Memphis, Tennessee
4) Industrial Construction Co., Eugene, Oregon

Table 5-1. WIGWAM BURNER MODIFICATIONS, COST ESTIMATES AND DELIVERY SCHEDULES, 1975*

Modification	Capital cost, $		Yearly cost, $		Time, months concept to operation
	40 foot burner	60 foot burner	40 foot burner	60 foot burner	
New, properly sized burner	40,000	70,000	8,000	10,000	6
Top damper	2,000	4,000	100	200	2
Overfire air dampers	400	600	40	60	1
Forced draft fan dampers	100	150	10	15	1
Fuel house & fuel regulating system	35,000	40,000	7,000	8,000	6
Fuel mixing system using cyclones & conveyors	7,000	9,000	1,500	2,000	6
Change of conveyors & cyclones for better fueling	1,500	2,000	150	200	3
Gas fired auxiliary burners[3]	3,000	4,500	3,000	4,500	6
Convert overfire air system to tangential flow	600	900	60	90	1
Convert overfire air system to manifold with blower & dampers	4,000	5,000	800	1,000	6
Add to the above for automatic control from exit temperature	3,000	4,000	600	800	8

* Costs and time schedules will vary with location

Table 5-1. WIGWAM BURNER MODIFICATIONS, COST ESTIMATES AND DELIVERY SCHEDULES, 1975*

Modification	Capital cost, $		Yearly cost, $		Time, months concept to operation
	40 foot burner	60 foot burner	40 foot burner	60 foot burner	
New grate system & forced draft fan	3,000	4,000	600	800	6
Thermocouple & recording pyrometer	500	500	100	100	2
Gas analysis recording (O_2 or CO_2)	2,000	2,000	500	500	3
Draft gauges & controls	500	500	50	50	1
Complete computer control system	15,000	20,000	3,000	4,000	12
Proper maintenance & operation including labor	1,000	1,000	2,000	2,000	1
Multiple cyclone particulate collector	25,000	70,000	5,000	14,000	12
Wet scrubber	40,000	120,000	12,000	36,000	12
Opacity monitoring system	10,000	12,000	1,000	1,200	6

* Costs and time schedules will vary with location

6. EMISSIONS FROM MODIFIED WIGWAM BURNERS

Not nearly as much data are available on emissions from modified wigwam burners as are available from simple wigwam burners. The data that are available may be more reliable, however, because it was obtained recently with modern equipment and methods. In some cases the actual emission data may not be measured but can be estimated from correlation with other known data, such as exit gas temperature.

WELL CONTROLLED BURNERS

Specific Tests

1. Tests on a fully modified wigwam burner with a top damper, manifolded and electronically controlled (as a function of exit temperature) overfire air system, balanced forced draft system and three propane fired auxiliary burners indicated a loading of 0.23 grains per standard cubic foot, corrected to 12% CO_2 at startup and an average value of 0.11 grains per standard cubic foot, corrected to 12% CO_2 under steady firing conditions and 800°F gas temperature. The opacity readings on this burner were 10% or less after initial startup. All three propane burners were used at startup and one was left on continuously throughout the day to aid in drying the wet fuel. The fuel was Douglas Fir bark and sawdust. At steady state firing, this burner was indicating 5.2% CO_2 and 15.0% O_2 for an exit gas analysis. (Publishers Paper Co., Liberal, Oregon)

2. A burner which had been modified by installing a top damper and a controlled, modulated overfire air system was tested over a wide range of varying air flows. The fuel was fed at a constant rate and was Douglas Fir bark and sawdust. With the air systems completely open the emissions were 0.14 grains per scf at 12% CO_2, about 10% - 15% opacity, 3.5% CO_2 and 16.0% O_2. With the dampers partially closed the emissions dropped to 0.07 grains per scf at 12% CO_2, 10% opacity, 5.7% CO_2 and 13.5% O_2. This burner was a relatively new, properly sized burner, free of air leaks, and with good maintenance. The exit gas temperature varied from a low value of 820°F with the dampers open to a high of 965°F with partial damper closure. Only limited damper adjustment was possible because the system had previously been set within narrow control limits based upon visual observations. This burner had been operated for several months in the 850°F - 950°F temperature range with no evidence of damage. (U.S. Plywood, Roseburg, Oregon)

3. An older burner was modified by changing the overfire air system from natural draft openings to 3 tangentially directed blowers. The blowers were controlled so that they operated individually. The burner was in excellent repair and was fired with a mixture of Douglas Fir and Hemlock, bark and sawdust. The test results are summarized in Table 6-1. (U.S. Plywood, Idanha, Oregon)

Table 6-1. MODIFIED WIGWAM BURNER TEST RESULTS

Test Conditions	Exit gas temp., °F	CO_2, %	O_2, %	Particulate emissions, $\frac{\text{Grain}}{\text{scf}}$ @ 12% CO_2	Opacity
Normal - all 3 blowers	750	3.0	17.0	0.22	10%
Only 2 blowers	940	5.6	14.4	0.09	0%
Normal - conveyor partially closed	860	3.6	16.5	0.15	10%

4. A highly modified wigwam burner was tested shortly after it was completed at the mill site. It had auxiliary burners for startup and a series of 4 separately controlled overfire air blowers which could be modulated to take in ambient air or any proportion of exhaust gas recirculated from just below the top damper. The damper system on these blowers was controlled by a thermostat at the top of the burner. The theory was that at high exit gas temperatures they were to take in ambient air to cool the fire and at low exit gas temperatures they were to recirculate the exit gases which would give a hotter fire. The recirculation ducts were not insulated and by the time the recirculated gases reached the overfire air blowers they were within 50°F of ambient air temperature. The fuel to this burner was very dirty, containing a large amount of clay and other inorganic matter from the dry handling of the logs. The fuel was a mixture of Englemann Spruce and White Fir, bark and sawdust. Because of the dirty fuel, the particulate emissions were primarily inorganic material. Both particulate loading and opacity were excessive, because of the high ash fuel being fed to the burner. The particulate

matter averaged 0.70 grains per standard cubic foot corrected to 12% CO_2 and the opacity was in the 20% - 40% range. The exit gas recirculation system did not seem to be effective in changing the emission significantly. The operator of the burner stated that, ".... it really smokes during the winter when the bark (fuel) is frozen." This burner again exhibited the fact that lower emissions are a function of higher temperature as shown in the results plotted as Figure 6-1. (Boise-Cascade, Council, Idaho)

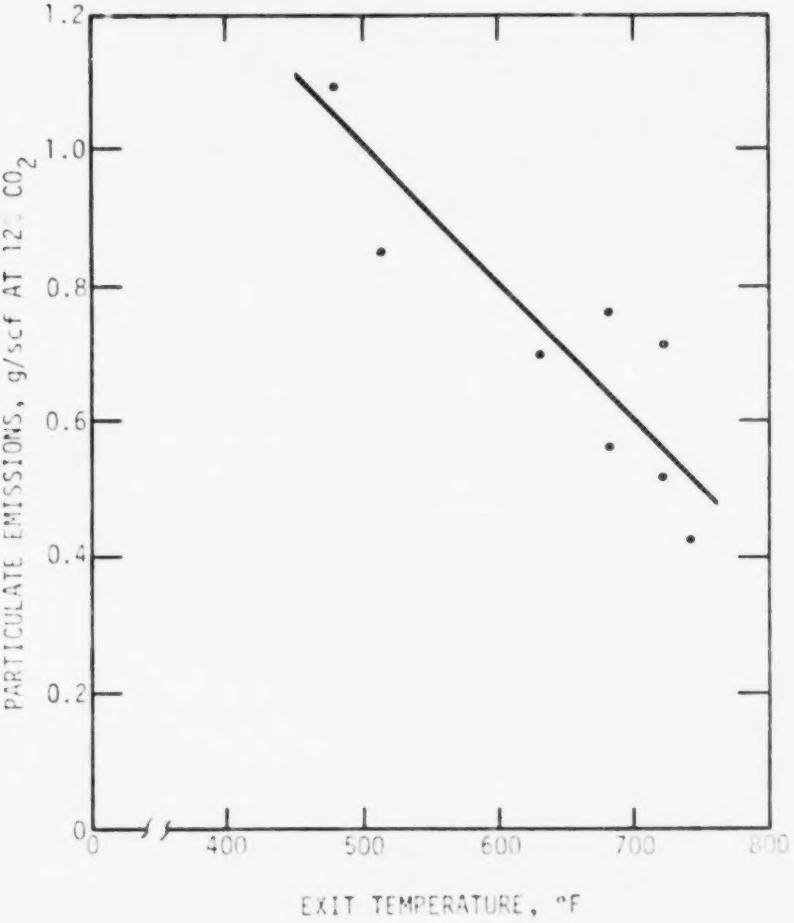

Figure 6-1. Particulate loading as a function of exit gas temperature for a modified Wigwam burner with dirty fuel (Boise-Cascade, Council, Idaho).

7. ALTERNATIVES TO WIGWAM BURNERS

If a mill must eliminate their wigwam burner they must go to alternative means of residue disposal. Some mills are disposing of all their residue at a profit and have not used a wigwam burner for years. Other mills in the same general area are convinced that the most economical method for them is to dispose of all of their residue in a wigwam burner. Since mill practices vary, and residues also vary, it becomes obvious that a thorough study must be done by each individual mill. This study consists of taking an accurate inventory of present and future residues, analyzing all alternatives for their costs and benefits, determining which alternatives are feasible and finally selecting the alternative, or set of alternatives, most favorable to the mill. When studying alternatives, a mill must be sure to establish costs for residue disposal by their presently used system. Many times mill operators have discovered that disposal by wigwam burner is one of the more expensive alternatives.

Conversion from a system burning the residue in a wigwam burner to an alternative system may not solve the pollution problem entirely. The alternative system selected also has some pollution potential which must be thoroughly analyzed and evaluated. The regulations governing the area where the alternatives may be applied must also be studied. Landfill regulations, for example, may be more restrictive than the regulations covering wigwam burners.

The following alternatives are some which might be considered for a medium sized mill (50,000 FBM/8 hr shift). Not all of the alternatives would apply to every mill and there may be other, more desirable alternatives for a specific mill, which are not even mentioned. Those mentioned have been tried and have been found satisfactory in specific situations.

RESIDUE CLASSIFICATION AND SEPARATION

Many of the alternative methods of residue disposal require rather exact material separation. If a mill is currently not concerned with residue separation this can be a large expense. If the bark must be removed to sell the white wood as bark free chips, a barker plus conveying system is required. Sawdust, chips, and planer shavings will need classification and then storage facilities at the mill site. New cyclones, conveyors, bins, and residue conversion systems such as chippers or hogs will be required. Since many alternatives involve initial classification and separation of residues, the costs of the system components are developed in Table 7-1 for inclusion with the alternatives mentioned later. Most of these systems will require 6 months to a year from conception to completion. The schedule and costs, of course, should be verified in advance.

Table 7-1. CLASSIFICATION AND SEPARATION UNIT COSTS, 1975[a,b]

System component	Capital outlay, $	Operating cost, $/Year[c]
Barker for 20" dia. logs w/motor & drive	50,000	4,000
Barker hog & conveyor system, in & out	45,000	3,000
Bark conveyor	10,000	500
Sawdust screening system	8,000	500
Sawdust shaving or chip storage bin	15,000	500
Chipping head w/motor & drive	40,000	8,000
Chipping knife grinder	10,000	1,000
Chipping conveyor system, in & out	15,000	1,000
Chipping building	10,000	500
Chip screen	8,000	500
Hog for fuel w/motor & drive	35,000	3,500
Hog conveyor system, in & out	20,000	1,500
Hogged fuel storage bin	10,000	300
Planer shavings screening system	8,000	500
Blower, blowpipe, and cyclone (each)	6,000	500

[a] Assume mill capacity 50 M FBM/8 hr shift.

[b] From report prepared for William Nelson, P.E., Anchorage, Alaska by Richard W. Boubel, P.E., and David C. Junge, P.E., Corvallis, Oregon, 1974.

[c] Does not include operators labor costs.

LANDFILL

Wood residue is similar to municipal refuse in that it contains a high percentage of organic material. Therefore, landfill practices and costs are very similar for the two residues. There are several factors that require investigation if wood and bark wastes are to be disposed of in a landfill. These factors include:

1. Haul distance, mill to landfill.
2. Landfill life at present and future mill production.
3. Fire hazards at landfill site.
4. Pollution of ground or surface water.
5. Gas evolution.
6. Settling of finished landfill.

The cost of disposal at a typical landfill site is approximately $1.50 per ton or $3.00 per unit. Trucking costs, for a 10 mile haul, are estimated to be about $1.00 per ton or $2.00 per unit. Landfill disposal of wood residue offers the mill no return for residue in terms of either money or energy.

Table 8-1 summarizes landfill costs as well as those for all other alternatives to burning in a wigwam burner. One note of caution concerning Table 8-1; the annual net cost or profit to the mill is calculated at the mill site. The distance of hauls and availability of markets will of course determine the actual net cost or profit.

SOIL ADDITIVES

Sawdust and bark have been used for years as mulches and soil amendments. These residues have been used by nurseries and garden stores around shrubs and flowers to retain moisture and beautify displays. Sawdust is used on highway cutbanks and along roadsides. Bark and sawdust can be used to lighten heavy soils, mulch orchards, provide drainage for wet lands, and help stabilize drifting sand dunes. Bark chunks are being used extensively for landscaping.

If the sawdust and bark could all be marketed, the mill would still be faced with disposal of other residues such as white wood and planer shavings. To amortize the large capital investment in the systems necessary for barking the logs it would probably be necessary to find markets for the shavings and chipped white wood.

CONVENIENCE FUELS

The two primary convenience fuels used in the U.S. are Presto-Logs and charcoal briquets. In some areas, bundled white wood or slab may also be sold for home use.

Presto-Logs, and some similar products, are made from primarily white wood residue which is compressed with or without a binder into a shape and size which is easily handled. These manufactured fuels retail for approximately 1¢ per pound which certainly looks attractive to a mill owner faced with 40 tons of white wood residue per day (40 tons per day X 2,000 pounds per ton X $0.01 per pound = $800 per day). The problem is the large installed equipment cost plus the limited market for the finished product, as well as transportation. Usually the manufacturer does not retail the product and a wholesale price of 1/2¢ per pound is more realistic.

Charcoal briquets are similar in that they retail for approximately 10¢ per pound. They are generally easier to handle because they are bagged after manufacture. A single mill could not consider a charcoal plant due to the cost (several million dollars). It might be a possibility in an area where several mills could construct and operate the plant cooperatively. Again, haul distances to the plant and for the finished product, size of plant, demand for the product, etc., should be carefully considered for an accurate estimate of costs and returns made before considering any expenditure on the plant.

WOOD FIBER USAGE

By far the largest usage of wood residue in the U.S. is for the fiber material it contains. Most paper pulp is made from wood fiber. White wood chips are preferred but varying small quantities of bark or sawdust can be incorporated. Chips, delivered to the pulp mill, are currently selling for approximately $20 per unit, although the price has been as high as $40 per unit at times past. The tremendous fluctuation in the price the pulp mills are willing to pay can turn a profit item into a loss for a mill. A thorough analysis of market conditions, transportation costs, contract arrangements, and the pulp mills' long range plans must be considered along with the usual concerns of equipment and labor costs at the forest products mill.

Shavings are in demand for particle board manufacture and small quantities are used for animal bedding. One must be cautious of relying heavily on particle board manufacturing to consume the mill residue. Lately, several particle board plants have closed because of the construction industry slump and mills have found themselves with planer shavings to dispose of. This has meant reactivating wigwam burners which had previously been retired. The same may be said for pulp chips. Today, a large amount of white wood which was previously chipped is being consumed in wigwam burners.

CHEMICAL EXTRACTIVES

Wood residue is a vast potential source of chemical raw materials. As the price of petrochemicals increases the economics of extraction of chemicals from wood becomes more favorable. Currently wax and cork are being profitably manufactured from Douglas Fir bark and as oil prices continue to increase,the economics look even more favorable. The bark is also a potential source for a wide variety of pharmaceutical chemicals and much research is directed toward this recovery and use.

The profitable extraction of chemicals from wood residue probably requires a parallel use for the wood fiber, either as fuel or raw material for pulp mills. There still needs to be considerable research on the size of extractive plants to achieve optimum utilization from the wood residue.

ALTERNATIVE INCINERATORS

The reason the wigwam incinerator is used so extensively by the forest products industry is that it does the job most economically. Any other type of incinerator that destroys the residue is, therefore, going to cost the mill more money. If a mill were to replace a wigwam burner with a more expensive type of incinerator they might want to go to a fuel bin system to obtain continuous feul feeding.

For example, if a mill is incinerating all the residue from 50 thousand board feet cut in an 8 hour shift, they would be feeding the wigwam approximately 60 tons of residue per 8 hours or 15,000 pounds per hour. If this was sent to a fuel storage bin and then taken from the bin at 5,000 pounds per hour for the entire 24 hour day, and a new incinerator operated continuously, a much smaller incinerator could be used. The savings in incinerator cost might pay for the fuel storage system plus the additional operation of 16 hours per day.

The multiple chamber type of incinerator is the most efficient destructor of combustible residue and also the most costly. The fuel would have to be hogged or somehow be reduced in size before going to the multiple chamber incinerator. Costs for a system using a multiple chamber incinerator approach those for a boiler plant (without the turbine) and can easily be 10 times the amount which would be spent for a new, properly sized wigwam burner.

The open pit incinerator or air curtain destructor has been advanced as the replacement for the wigwam burner but it has not been proven as the universal solution. These open pit incinerators, with ducted overfire air systems, are not capable of consuming small sized fuel particles such as sawdust and planer shavings. The particulate air pollution from these burners using light fuels is unacceptable in both grain loading and opacity. They do work fairly well on large material such as slabs and edgings and possibly could be used in a mill where a market for the light fuels was nearby.

DIRECT ENERGY PRODUCTION

Wood fired boilers have been in existence nearly as long as the forest products industry. The original boiler type, which is still widely used today, is the dutch oven, which relies on large masses of refractory material to dry and then gasify the fuel. The combustible gases then travel to a second chamber where additional air is added and combustion completed. The hot gases then flow to the boiler.

Spreader stokers rely on hot air from a stack air heater to dry the fuel and start gasification. The combustion reaction occurs in a water walled boiler and much of the energy is transferred as radiant heat.

Both the dutch oven and spreader stokers are used with boilers to generate process steam or electricity for mill or public uses. As energy prices increase rapidly, wood residue is re-entering the energy picture. Many large mills are installing new boiler capacity to make themselves "energy independent." Smaller mills that are dependent upon electricity, oil, or natural gas may find that suddenly their wood residue, which had previously been incinerated, is now a relatively high value item. Hogged fuel prices at the mill site have gone from about 50¢ to over $4.00 per unit in just a few years. At todays energy prices, the $ energy equivalent of a unit of hogged fuel is approximately $25.00.

Suspension burners are being used with both incinerators and boilers. The fuel must be relatively dry and finely divided before firing with a suspension burner (dry plywood sander dust makes an excellent fuel). Suspension burners require surge prevention in their fuel system to maintain a steady flame with fluctuating fuel supplies. Heavy surges of fine dry fuel can lead to dense black smoke issuing from the boiler stack. To use suspension burners on the total wood residue from a mill would require extensive fuel drying facilities (capital cost of approximately $100,000 for a 50 M FBM mill) and grinding or hammermilling facilities. These facilities would be in addition to the other, usual boiler costs.

Fuel cells have been suggested as an alternative to spreader stokers, dutch ovens, and suspension burning. A fuel cell is best described as a combination of all three of these systems. The fuel must be in finely divided state (but not as fine as for suspension burning) and introduced with a primary air supply. Hot air is added tangentially in a cylindrical, refractory lined chamber which serves to dry and gasify the fuel. The hot gases then pass from the fuel cell into the boiler section. Some fuel cells attain such a high temperature that the ash may be drawn off as a liquid slag. Fuel cells show some future promise but currently the problems of control, non-uniformity of fuel, and refractory problems appear to limit their use.

Other combustion systems for wood fuel can be mentioned as future possibilities, not practical at this time. Included in this category would be fluidized bed combustion, direct fired gas turbines, and hot air engines of various types.

CONVERSION TO OTHER FUELS

Wood as a fuel raw material is generally thought of in its native, solid form. Conversion to other forms is possible and in many cases practical to extend liquid and gaseous fuels. Wood burning automobiles, trucks, and buses are occasionally pictured in the news. Usually these have generators that convert the carbon in the wood into CO and other combustible gases which are directed to the engine where they burn to give energy.

A more practical, and acceptable alternative appears to be the conversion of wood residue to methanol (methyl alcohol) or ethanol (ethyl alcohol) for use as a gasoline substitute. Current automobiles can be operated on mixtures up to 30% methanol in gasoline with only minor tune-up changes. Vehicles operating on 100% methanol could be designed if necessary. Many research projects are now looking into methanol (and ethanol) as gasoline substitutes. Wood residue, along with agricultural products, is a renewable energy resource which could ease the gasoline shortages predicted for the U. S.

Pyrolysis is a process of distilling a material with heat to break it into its gaseous, liquid, and solid components. Wood residue is an excellent material to use as the raw material for pyrolysis. Turpentine, wood tars, and gaseous, liquid, and solid hydrocarbons are just some of the materials that are currently being produced by pyrolysis. Through pyrolysis it is possible to produce substitutes for current gaseous and liquid fuels, using solid fuels, such as wood, as both the raw material and source of heat energy.[8]

Pyrolytic decomposition is still in the investigation stage for wood residue distillation and disposal and no firm cost data is available at this time.

Table 8-1. COSTS, VALUES RECOVERED, TIME SCHEDULES, AND POLLUTIONAL POTENTIAL FOR ALTERNATIVES TO WIGWAM BURNERS[a]

Alternative	System needed at mill with units per day processed	Capital cost, $	Annual operating cost[b], $	Recovered products, value & unit	Annual value recovered in products or energy, $	Annual net cost to mill or (excess return)[c], $	Time to install total system, months	Potential pollution from new system
Landfill, 10 mile haul	Storage bin 10 units	10,000	39,000	None	None	37,000	2	Solid waste, possible water pollution
Bark logs, bark & sawdust sold, white wood chipped & sold, planer shavings sold	Barker 8 units, storage bin 10 units, sawdust 5 units, bin 10 units, chipping system 11 units, chip bin 10 units, planer shavings system & storage 5 units, 3 new cyclone systems	252,000	21,300	Bark $8.00/unit Sawdust $6.00/unit Chips $25.00/unit Shavings $8.00/unit Total	16,000 7,500 68,750 10,000 102,250	(80,950)	12 - 18	Some fugitive dust at loading systems
Hog & mix mill residue, sell as mixed hog fuel	Hog system 18 units, storage bin 2 at 10 units, 2 new conveyor systems, 2 new cyclone systems	97,000	7,600	Mixed hogged fuel $4.00/unit	30,000	(22,400)	9 - 15	Some fugitive dust
Hog & mix all residue, fire in own boiler for energy	Hog system 18 units, storage bin 2 at 10 units 2 new conveyor systems, 2 new cyclone systems, wood-fired boiler with wet scrubber & turbine generator	950,000	80,000	Mixed hogged fuel @ $20.00 per unit energy equivalent	150,000	(70,000)	18 - 36	Boiler emissions range from controlled @ 0.05 grains/SCF to uncontrolled 0.5 grains per SCF
Multiple chamber incinerator for all residue	Hog system 18 units, storage bin 2 at 10 units, 2 new conveyor systems, 2 new cyclone systems, multiple chamber incinerator for 2.5 units / hour (24 hours)	500,000	20,000	None	None	20,000	18 - 36	Incinerator emissions about same range as boiler emissions
Air curtain destructor for all residue[a]	Air curtain destructor for 4 units per hour (8 hours daily operation)	80,000	8,000	None	None	8,000	6 - 8	Emissions approximately 0.1-0.2 grains per SCF
Air curtain destructor for bark & course residue, sell sawdust and planer shavings[a]	Air curtain destructor for 3 units per hour (8 hours daily operation) sawdust 5 units, bin 10 units, planer shavings system & storage 5 units, 2 new cyclone systems	106,000	8,000	Sawdust $6.00/unit Shavings $8.00/unit Total	7,500 10,000 17,500	(9,500)	6 - 8	Same as for air curtain destructor above
Make logs & sell bark, all other to Presto-log plant	Barker 8 units, storage bin for bark 10 units, chipping system 11 units, 3 new cyclone systems, Presto-log plant (3 employees to operate)	498,000	49,500	Bark $8.00/unit Presto-Logs @ 1¢/lb Total	16,000 100,000 116,000	(66,500)	12 - 18	Some fugitive dust

a Data from Drisall, Corp., Attica, Indiana (for mill producing approximately 50,000 board feet per 8 hour shift.)
b Not including labor costs.
c Not including any capital costs. At mill site except landfill.

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APPENDIX A

Oregon State Sanitary Authority Regulations: Construction and Operation of Wigwam Waste Burners

SUBDIVISION 9

CONSTRUCTION AND OPERATION OF WIGWAM WASTE BURNERS

[ED. NOTE: Unless otherwise specified, sections 24-005 through 24-[illegible] of this Chapter of the Oregon Administrative Rules Compilation were adopted by the State Sanitary Authority June [illegible], 1968 and filed with the Secretary of State, July [illegible], 1968 as Administrative Order SA [illegible].]

24-005 DEFINITIONS. (1) "Approved" means approved in writing by the Sanitary Authority [illegible].

(2) "[illegible] Waste" means all carbonaceous material which is readily combustible including [illegible] planer ends, slabs and sawdust.

(3) "Overfire Air" means air introduced directly into the waste burner through upper openings [illegible] around the release of the fire.

(4) "Underfire Air" means air introduced into the waste burner under the fuel pile.

(5) "Wigwam Waste Burner" means a burner which consists of a single combustion chamber, has the general features of a truncated cone, and is used for the incineration of wood wastes.

24-010 WIGWAM WASTE BURNERS—PURPOSE. Section 24-010 through Section 24-[illegible] are adopted for the purpose of preventing or minimizing the emission of [illegible] [illegible] and [illegible] which result from [illegible] the use of wigwam waste burners.

24-015 WIGWAM WASTE BURNERS—CONSTRUCTION, [illegible] [illegible] [illegible] [illegible]

(3) Adjustment of forced draft underfire air shall be by variable speed blower or fans, dampers or by-passes or by other approved means.

(4) The principal source of overfire air shall be primarily by adjustable tangential air ports located near the base of the wigwam waste burner or by other approved means.

(5) A thermometer or other approved temperature [illegible] shall be installed [illegible]. The thermocouple shall be installed at the [illegible] of a [illegible] feet above and near the center of the [illegible] or at another approved location.

(6) [illegible] shall be [illegible] as [illegible] as possible [illegible] combustion.

(7) A daily record of the waste burner operation shall be maintained [illegible] temperature [illegible] shall be submitted to the Sanitary Authority within [illegible].

(8) Auxiliary fuel shall be used as necessary during start up and during periods of poor combustion to maintain [illegible] temperatures required under [illegible].

(9) [illegible] materials which cause excess discharge [illegible] in violation of Section [illegible] shall not be used as auxiliary fuels.

(10) [illegible] waste shall be [illegible] into the burner [illegible].

24-0[illegible] [illegible]. (1) A [illegible] [illegible]

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(2) Wigwam waste burners located in sparsely populated areas of the state where their potential for causing an air pollution problem in the immediate or surrounding area is slight, may be granted variances from the provisions of Section 24-020 pursuant to ORS 449.810.